

CSE211 Digital Design

Akdeniz University

Week04-05: Boolean Algebra and Logic Gates

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Course program

Week 01	2-Oct-23	Introduction
Week 02	9-Oct-23	Digital Systems and Binary Numbers I
Week 03	16-Oct-23	Digital Systems and Binary Numbers II
Week 04	23-Oct-23	Boolean Algebra and Logic Gates I
Week 05	30-Oct-23	Boolean Algebra and Logic Gates II
Week 06	6-Nov-23	Gate Level Minimization
Week 07	13-Nov-23	Karnaugh Maps
Week 08	20-Nov-23	Midterm
Week 09	27-Nov-23	Karnaugh Maps
Week 10	4-Dec-23	Combinational Logic
Week 11	11-Dec-23	Combinational Logic
Week 12	18-Dec-23	Timing, delays and hazards
Week 13	25-Dec-23	Synchronous Sequential Logic
Week 14	1-Jan-24	Synchronous Sequential Logic

Previous chapter terms to know

- DVD (Digital Versatile Disc)
- GUI (Graphical User Interface)
- BCD (Binary Coded Decimal)
- ASCII (American Standard Code for Information Interchange)
- STX (Start of Text)
- ETX (End of Text)
- CR (Carriage Return)
- HDL (Hardware Description Language)

Boolean Algebra

- Boolean algebra is a mathematical system for the manipulation of variables that can have one of two values.
 - In formal logic, these values are “true” and “false.”
 - In digital systems, these values are “on” and “off,” 1 and 0, or “high” and “low.”
- Boolean expressions are created by performing operations on Boolean variables.
 - Common Boolean operators include AND, OR, and NOT.

Boolean Algebra – Truth Table

- A Boolean operator can be completely described using a **truth table**.
- The truth table for the Boolean operators AND and OR are shown at the right.
- The AND operator is also known as a Boolean product. The OR operator is the Boolean sum.

X AND Y

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1

X OR Y

X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1

Boolean Algebra – Truth Table

- The truth table for the Boolean NOT operator is shown at the right.
- The NOT operation is most often designated by an **overbar**. It is sometimes indicated by a **prime mark** (') or an “elbow” (\neg).

NOT x	
x	\overline{x}
0	1
1	0

Boolean Algebra – Boolean Functions

- A Boolean function has:
 - At least one Boolean variable,
 - At least one Boolean operator, and
 - At least one input from the set $\{0,1\}$.
- It produces an **output** that is also a member of the **set $\{0,1\}$** .

Now you know why the binary numbering system is so handy in digital systems.

Boolean Algebra – Boolean Functions

- The truth table for the Boolean function:

$$F(x, y, z) = x\bar{z} + y$$

is shown at the right.

- To make evaluation of the Boolean function easier, the truth table contains extra (shaded) columns to hold evaluations of subparts of the function.

$$F(x, y, z) = x\bar{z} + y$$

x	y	z	\bar{z}	$x\bar{z}$	$x\bar{z} + y$
0	0	0	1	0	0
0	0	1	0	0	0
0	1	0	1	0	1
0	1	1	0	0	1
1	0	0	1	1	1
1	0	1	0	0	0
1	1	0	1	1	1
1	1	1	0	0	1

Boolean Algebra – Rules of precedence

- As with common arithmetic, Boolean operations have **rules of precedence**
- The **NOT** operator has highest priority, followed by AND and then OR.
- This is how we chose the (shaded) function subparts in our table.

$$F(x, y, z) = x\bar{z} + y$$

x	y	z	\bar{z}	$x\bar{z}$	$x\bar{z} + y$
0	0	0	1	0	0
0	0	1	0	0	0
0	1	0	1	0	1
0	1	1	0	0	1
1	0	0	1	1	1
1	0	1	0	0	0
1	1	0	1	1	1
1	1	1	0	0	1

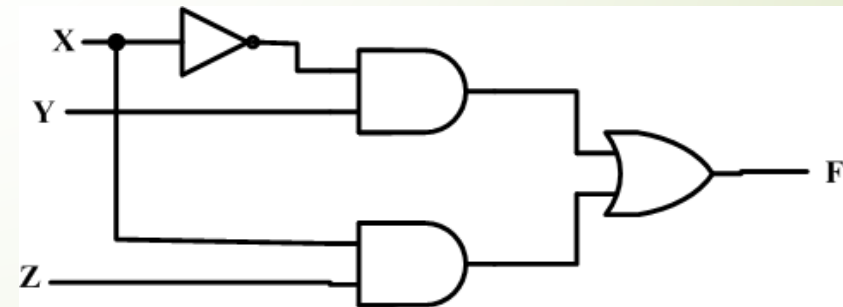
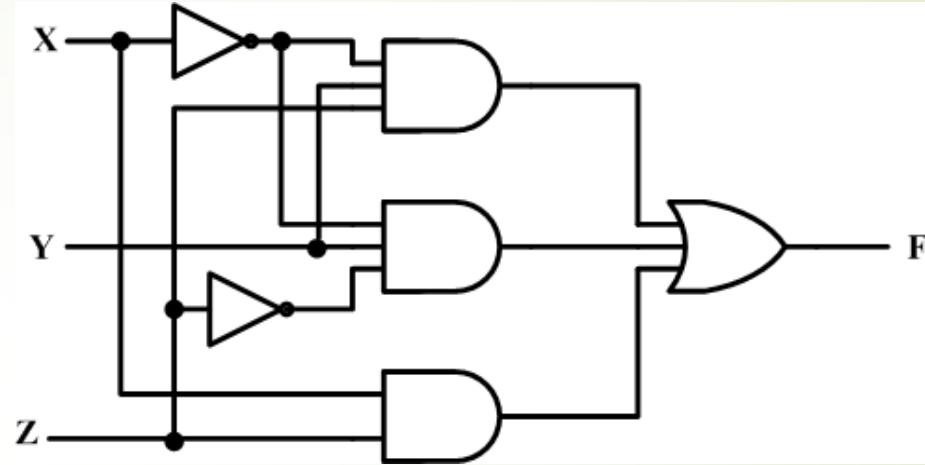
Boolean Algebra – Simplification

- Digital computers contain circuits that implement Boolean functions.
- The simpler that we can make a Boolean function, the smaller the circuit that will result.
 - Simpler circuits are cheaper to build, consume less power, and run faster than complex circuits.
- With this in mind, we always want to reduce our Boolean functions to their simplest form.
- There are a number of Boolean identities that help us to do this.

Boolean Algebra – Affect on implementation

➤ $F = X'YZ + X'YZ' + XZ$

➤ Reduces to $F = X'Y + XZ$



Boolean Algebra – Laws

- Most Boolean identities have an AND (product) form as well as an OR (sum) form. We give our identities using both forms. Our first group is rather intuitive:

Identity Name	AND Form	OR Form
Identity Law	$1x = x$	$0 + x = x$
Null Law	$0x = 0$	$1 + x = 1$
Idempotent Law	$xx = x$	$x + x = x$
Inverse Law	$x\bar{x} = 0$	$x + \bar{x} = 1$

Boolean Algebra – Laws (Cont.)

- Our second group of Boolean identities should be familiar to you from your study of algebra:

Identity Name	AND Form	OR Form
Commutative Law	$xy = yx$	$x+y = y+x$
Associative Law	$(xy)z = x(yz)$	$(x+y)+z = x+(y+z)$
Distributive Law	$x+yz = (x+y)(x+z)$	$x(y+z) = xy+xz$

- Using **distributive law** $x+x'y=(x+x')(x+y)$

Boolean Algebra – Laws (Cont.)

- Our last group of Boolean identities are perhaps the most useful.
- If you have studied set theory or formal logic, these laws are also familiar to you.

Identity Name	AND Form	OR Form
Absorption Law	$x(x+y) = x$	$x + xy = x$
DeMorgan's Law	$\overline{(xy)} = \bar{x} + \bar{y}$	$\overline{(x+y)} = \bar{x}\bar{y}$
Double Complement Law	$\overline{(\bar{x})} = x$	

Boolean Algebra – DeMorgan's Law

- Sometimes it is more economical to build a circuit using the complement of a function (and complementing its result) than it is to implement the function directly.
- DeMorgan's law provides an easy way of finding the complement of a Boolean function.
- Recall **DeMorgan's law** states:

$$\overline{(xy)} = \bar{x} + \bar{y} \quad \text{and} \quad \overline{(x+y)} = \bar{x}\bar{y}$$

Boolean Algebra – Proof: DeMorgan

Theorem 3.7: DeMorgan's Law

For each pair of elements x, y in a Boolean algebra:

$$\overline{(x + y)} = \bar{x} \cdot \bar{y}$$

$$\overline{(x \cdot y)} = \bar{x} + \bar{y}$$

Proof:

$$\begin{aligned}(x + y) + \bar{x} \cdot \bar{y} &= (x + y + \bar{x}) \cdot (x + y + \bar{y}) \\&= (x + \bar{x} + y) \cdot (y + \bar{y} + x) \\&= (1 + y) \cdot (1 + x) \\&= 1 \cdot 1 \\&= 1\end{aligned}$$

Note: Using
Associativity of
each operation
(+), (·)

Boolean Algebra – DeMorgan's Law (Cont.)

- DeMorgan's law can be extended to any number of variables.
- Replace each variable by its complement and change all ANDs to ORs and all ORs to ANDs.
- Thus, we find the **complement** of:

$$F(X, Y, Z) = (XY) + (\bar{X}Z) + (Y\bar{Z})$$

is:
$$\begin{aligned}\bar{F}(X, Y, Z) &= \overline{(XY) + (\bar{X}Z) + (Y\bar{Z})} \\ &= \overline{(XY)} \cdot \overline{(\bar{X}Z)} \cdot \overline{(Y\bar{Z})} \\ &= (\bar{X} + \bar{Y})(X + \bar{Z})(\bar{Y} + Z)\end{aligned}$$

Truth Tables for the Laws of Boolean

Boolean Expression	Description	Equivalent Switching Circuit	Boolean Algebra Law or Rule
$A + 1 = 1$	A in parallel with closed = "CLOSED"		Annulment
$A + 0 = A$	A in parallel with open = "A"		Identity
$A \cdot 1 = A$	A in series with closed = "A"		Identity
$A \cdot 0 = 0$	A in series with open = "OPEN"		Annulment
$A + A = A$	A in parallel with A = "A"		Idempotent
$A \cdot A = A$	A in series with A = "A"		Idempotent

Boolean Expression	Description	Equivalent Switching Circuit	Boolean Algebra Law or Rule
$NOT \bar{A} = A$	NOT NOT A (double negative) = "A"		Double Negation
$A + \bar{A} = 1$	A in parallel with NOT A = "CLOSED"		Complement
$A \cdot \bar{A} = 0$	A in series with NOT A = "OPEN"		Complement
$A+B = B+A$	A in parallel with B = B in parallel with A		Commutative
$A \cdot B = B \cdot A$	A in series with B = B in series with A		Commutative
$\overline{(A+B)} = \bar{A} \cdot \bar{B}$	invert and replace OR with AND		de Morgan's Theorem
$\overline{(A \cdot B)} = \bar{A} + \bar{B}$	invert and replace AND with OR		de Morgan's Theorem

Boolean Algebra – Complement of Functions

EXAMPLE 2.2

Find the complement of the functions $F_1 = x'yz' + x'y'z$ and $F_2 = x(y'z' + yz)$. By applying DeMorgan's theorems as many times as necessary, the complements are obtained as follows:

$$F_1' = (x'yz' + x'y'z)' = (x'yz')'(x'y'z)' = (x + y' + z)(x + y + z')$$

$$\begin{aligned} F_2' &= [x(y'z' + yz)]' = x' + (y'z' + yz)' = x' + (y'z')'(yz)' \\ &= x' + (y + z)(y' + z') \\ &= x' + yz' + y'z \end{aligned}$$

Boolean Algebra – Principle of Duality

- What is meant by the dual of a function?
 - The *dual* of a function is obtained by interchanging OR and AND operations and replacing 1s and 0s with 0s and 1s.
- Shortcut to getting function complement
 - Having $F = X'YZ' + X'Y'Z$
 - Generate the dual $F = (X' + Y + Z')(X' + Y' + Z)$
 - Complement each literal to get:
 - $F' = (X + Y' + Z)(X + Y + Z')$
- Each postulate consists of two expressions s.t. one expression is transformed into the other by interchanging the operations (+) and (·) as well as the identity elements 0 and 1.
- Such expressions are known as duals of each other.
- If some equivalence is proved, then its dual is also immediately true.
- E.g. If we prove: $(x \cdot x) + (\bar{x} \cdot \bar{x}) = 1$, then we have by duality: $(x + x) \cdot (\bar{x} + \bar{x}) = 0$

Boolean Algebra – Principle of Duality (Cont.)

- There are useful identities of Boolean expressions that can help us to transform an expression A into an equivalent expression B
- We can derive additional identities with the help of the **dual** of a Boolean expression.
- The dual of a Boolean expression is obtained by interchanging Boolean sums and Boolean products and interchanging 0s and 1s.

Boolean Algebra – Duality

► Examples:

The dual of $x(y + z)$ is $x + yz$

The dual of $x \cdot 1 + (y + z)$ is $(x + 0)(yz)$

The **dual** of a Boolean function F represented by a Boolean expression is the function represented by the dual of this expression.

This dual function, denoted by F_d , does not depend on the particular Boolean expression used to represent F .

Boolean Algebra – Duality

- Therefore, an identity between functions represented by Boolean expressions **remains valid** when the duals of both sides of the identity are taken.
- We can use this fact, called the **duality principle**, to derive new identities.
- For example, consider the absorption law $x(x + y) = x$
- By taking the duals of both sides of this identity, we obtain the equation $x + xy = x$, which is also an identity (and also called an absorption law).

Boolean Algebra – Example

- We can use Boolean identities to simplify the function: $F(X, Y, Z) = (X + Y)(X + \bar{Y})(\overline{XZ})$ as follows:

$$\begin{aligned}
 & (X + Y)(X + \bar{Y})(\overline{XZ}) \\
 & (X + Y)(X + \bar{Y})(\bar{X} + Z) \\
 & (XX + X\bar{Y} + XY + Y\bar{Y})(\bar{X} + Z) \\
 & ((X + Y\bar{Y}) + X(Y + \bar{Y}))(\bar{X} + Z) \\
 & ((X + 0) + X(1))(\bar{X} + Z) \\
 & X(\bar{X} + Z) \\
 & X\bar{X} + XZ \\
 & 0 + XZ \\
 & XZ
 \end{aligned}$$

Idempotent Law (Rewriting)
 DeMorgan's Law
 Distributive Law
 Commutative & Distributive Laws
 Inverse Law
 Idempotent Law
 Distributive Law
 Inverse Law
 Idempotent Law

Boolean Algebra Simplification

Example

$$Q = (A + B).(A + C)$$

$$A.A + A.C + A.B + B.C \text{ – Distributive law}$$

$$A + A.C + A.B + B.C \text{ – Idempotent AND law (} A.A = A \text{)}$$

$$A(1 + C) + A.B + B.C \text{ – Distributive law}$$

$$A.1 + A.B + B.C \text{ – Identity OR law (} 1 + C = 1 \text{)}$$

$$A(1 + B) + B.C \text{ – Distributive law}$$

$$A.1 + B.C \text{ – Identity OR law (} 1 + B = 1 \text{)}$$

$$Q = A + (B.C) \text{ – Identity AND law (} A.1 = A \text{)}$$

Boolean Algebra – Summary

Table 2.1
Postulates and Theorems of Boolean Algebra

Postulate 2	(a)	$x + 0 = x$	(b)	$x \cdot 1 = x$
Postulate 5	(a)	$x + x' = 1$	(b)	$x \cdot x' = 0$
Theorem 1	(a)	$x + x = x$	(b)	$x \cdot x = x$
Theorem 2	(a)	$x + 1 = 1$	(b)	$x \cdot 0 = 0$
Theorem 3, involution		$(x')' = x$		
Postulate 3, commutative	(a)	$x + y = y + x$	(b)	$xy = yx$
Theorem 4, associative	(a)	$x + (y + z) = (x + y) + z$	(b)	$x(yz) = (xy)z$
Postulate 4, distributive	(a)	$x(y + z) = xy + xz$	(b)	$x + yz = (x + y)(x + z)$
Theorem 5, DeMorgan	(a)	$(x + y)' = x'y'$	(b)	$(xy)' = x' + y'$
Theorem 6, absorption	(a)	$x + xy = x$	(b)	$x(x + y) = x$

Boolean Algebra – Simplification

Simplify the following Boolean functions to a minimum number of literals.

1. $x(x' + y) = xx' + xy = 0 + xy = xy.$

2. $x + x'y = (x + x')(x + y) = 1(x + y) = x + y.$

3. $(x + y)(x + y') = x + xy + xy' + yy' = x(1 + y + y') = x.$

4.
$$\begin{aligned} xy + x'z + yz &= xy + x'z + yz(x + x') \\ &= xy + x'z + xyz + x'yz \\ &= xy(1 + z) + x'z(1 + y) \\ &= xy + x'z. \end{aligned}$$

5. $(x + y)(x' + z)(y + z) = (x + y)(x' + z),$ by duality from function 4.

Boolean Algebra – Simplification

➤ Find the simplified equivalent for the following equations

➤ $a(a+b')$

➤ $a.a+a.b'=a+a.b'=a.(1+b)=a.1=a$

➤ $a+(a'+b)'$

➤ $a+(a')'.b'=a+ab'=a$

➤ $x.y+x'.z+y.z+y'z$

➤ $xy+z$

➤ $xyz+x'yz+y'z$

➤ z

Boolean Algebra – Simplification

- $A.(A'+B)=?$
- $(A+B).(A+C)=?$
- $F=A'.B+A+A.B=?$
- $A.B+A'C+B.C$
- $A'B'C' + A'B'C + ABC' + AB'C'$

$$A.B+A'.C$$

Boolean Algebra – Simplification

$$\begin{aligned} F(A,B,C) &= A' B' C' + A' B' C + A B' C' + A B' C + A B C' + A B C \\ &= A' B' (C' + C) + A B' (C' + C) + A B (C' + C) \\ &= A' B' + A B' + A B \\ &= A' B' + A B' + A B + \mathbf{A B'} \\ &= B' (A' + A) + \mathbf{A} (B + \mathbf{B'}) \\ &= B' + A \end{aligned}$$

Boolean Algebra – Simplification

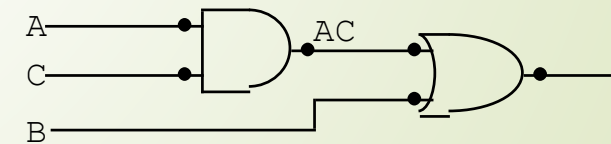
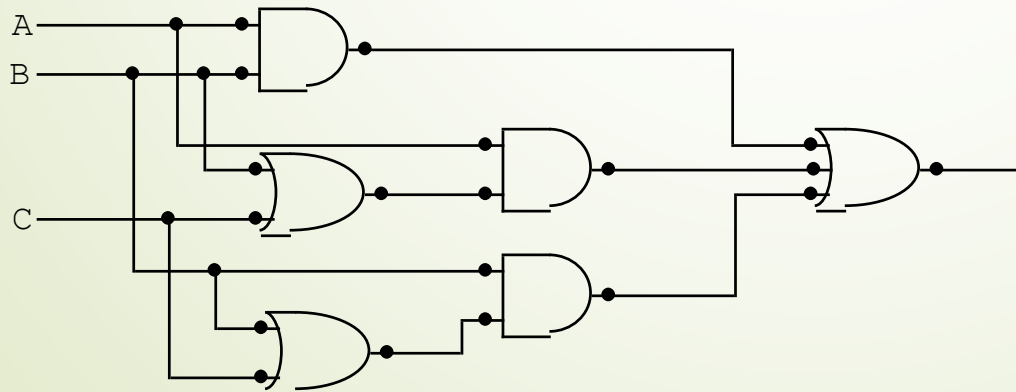
$$\blacksquare AB + A(B + C) + B(B + C)$$

$$= AB + AB + AC + BB + BC$$

$$= AB + AC + B + BC$$

$$= AB + AC + B$$

$$= AC + B$$



Boolean Algebra – Logically Equivalent Expressions

- Through our exercises in simplifying Boolean expressions, we see that there are numerous ways of stating the same Boolean expression.
 - These “synonymous” forms are **logically equivalent**.
 - **Logically equivalent expressions have identical truth tables.**
- In order to eliminate as much confusion as possible, designers express Boolean functions in **standardized or canonical form**.

Boolean Algebra – Sum of Products and Product of Sums

- There are two canonical forms for Boolean expressions: **sum-of-products** and **product-of-sums**.
 - Recall the Boolean product is the AND operation and the Boolean sum is the OR operation.
- In the **sum-of-products** form, ANDed variables are ORed together.
 - For example:
$$F(x, y, z) = xy + xz + yz$$
- In the **product-of-sums** form, ORed variables are ANDed together.
 - For example:
$$F(x, y, z) = (x+y)(x+z)(y+z)$$

Boolean Algebra – Normal Forms

- Consider the function:

$$f(w, x, y, z) = \bar{x} + w\bar{y} + \bar{w}yz$$

- A **literal** is an occurrence of a complemented or uncomplemented variable in a formula.
- A **product term** is either a literal or a product (conjunction) of literals.
- **Disjunctive normal form**: A Boolean formula written as a single product term or as a sum (disjunction) of product terms.

Boolean Algebra – Normal Forms

- Consider the function:

$$f(w, x, y, z) = z(x + \bar{y})(w + \bar{x} + \bar{y})$$

- A **sum term** is either a literal or a sum (disjunction) of literals.
- **Conjunctive normal form**: A Boolean formula written as a single sum term or as a product (conjunction) of sum terms.

Boolean Algebra – Canonical Formulas

- How to obtain a Boolean formula given a truth table?

X	Y	Z	f
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

Boolean Algebra – Minterm Canonical Formula

X	Y	Z	f
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

$$\bar{x} \bar{y} z$$

$$\bar{x} y z$$

$$x \bar{y} \bar{z}$$

$$f(x, y, z) = \bar{x} \bar{y} z + \bar{x} y z + x \bar{y} \bar{z}$$

Boolean Algebra – m-Notation

X	Y	Z	f
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

$$\bar{x} \bar{y} z$$

$$\bar{x} y z$$

$$x \bar{y} \bar{z}$$

- $f(x, y, z)$ can be written as $f(x, y, z) = m_1 + m_3 + m_4$
- $f(x, y, z) = \Sigma m(1, 3, 4)$

Boolean Algebra – Maxterm Canonical Formula

X	Y	Z	f
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

$$x + y + z$$

$$x + \bar{y} + z$$

$$\bar{x} + y + \bar{z}$$

$$\bar{x} + \bar{y} + z$$

$$\bar{x} + \bar{y} + \bar{z}$$

$$f(x, y, z) = (x + y + z)(x + \bar{y} + z)(\bar{x} + y + \bar{z})(\bar{x} + \bar{y} + z)(\bar{x} + \bar{y} + \bar{z})$$

Boolean Algebra – Sum of Products

- It is easy to convert a function to sum-of-products form using its truth table.
- We are interested in the values of the variables that make the function true (=1).
- Using the truth table, we list the values of the variables that result in a true function value.
- Each group of variables is then ORed together.

$$F(x, y, z) = x\bar{z} + y$$

x	y	z	$x\bar{z} + y$
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

Boolean Algebra – Sum of Products

- The **sum-of-products** form for our function is:

$$F(x, y, z) = \bar{x}y\bar{z} + \bar{x}yz + x\bar{y}\bar{z} + x\bar{y}z + x\bar{y}z + xyz$$

We note that this function is **not in simplest terms**. Our aim is only to rewrite our function in **canonical sum-of-products form**.

$$F(x, y, z) = x\bar{z} + y$$

x	y	z	$x\bar{z} + y$
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

CNF and DNF

- Find the f function using both DNF and CNF for the following truth tables

X	Y	f
0	0	0
0	1	1
1	0	1
1	1	0

X	Y	f
0	0	1
0	1	1
1	0	1
1	1	1

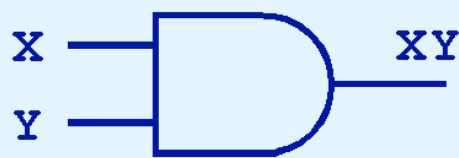
X	Y	Z	f
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Logic Gates

- We have looked at Boolean functions in abstract terms.
- In this section, we see that **Boolean functions are implemented in digital computer circuits called gates.**
- **A gate is an electronic device that produces a result based on two or more input values.**
 - **In reality, gates consist of one to six transistors,** but digital designers think of them as a single unit.
 - **Integrated circuits** contain collections of gates suited to a particular purpose.

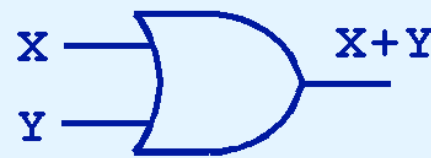
Logic Gates – AND OR NOT

- The three simplest gates are the **AND**, **OR**, and **NOT** gates.



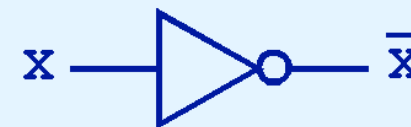
X AND Y

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1



X OR Y

X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1

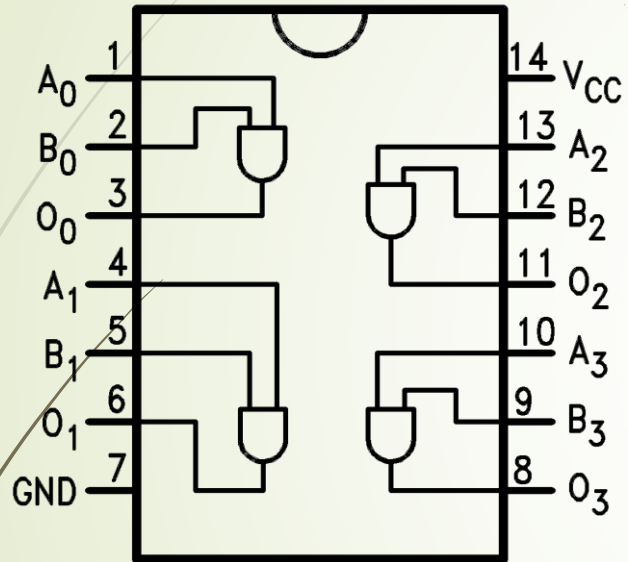


NOT X

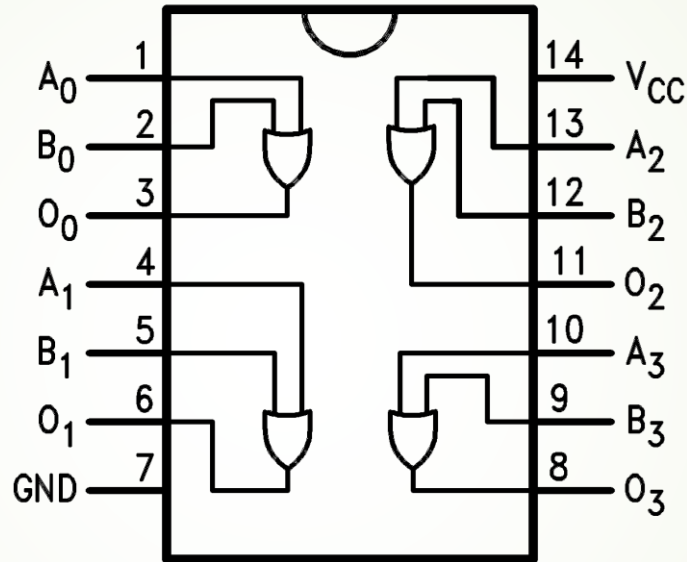
X	\bar{X}
0	1
1	0

- They correspond directly to their respective Boolean operations, as you can see by their truth tables.

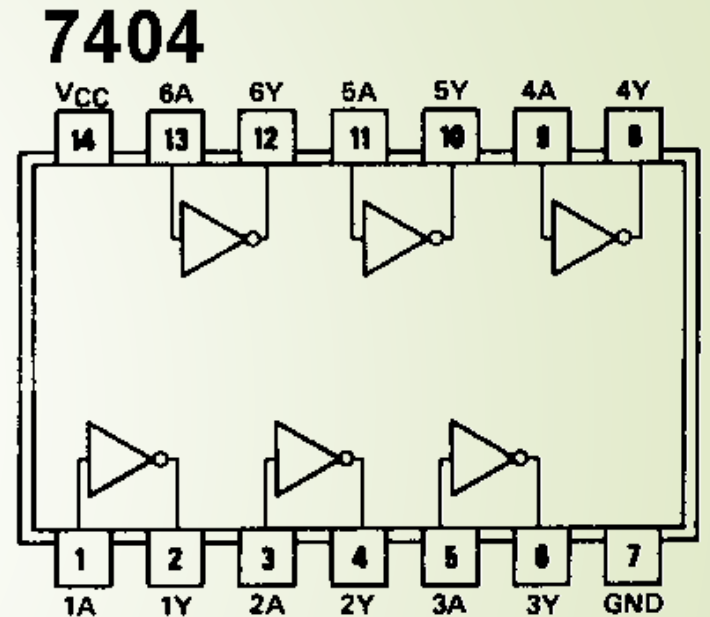
Logic Gates – AND OR NOT



74AC08, 74ACT08
Quad 2-Input AND Gate



74AC32, 74ACT32
Quad 2-Input OR Gate



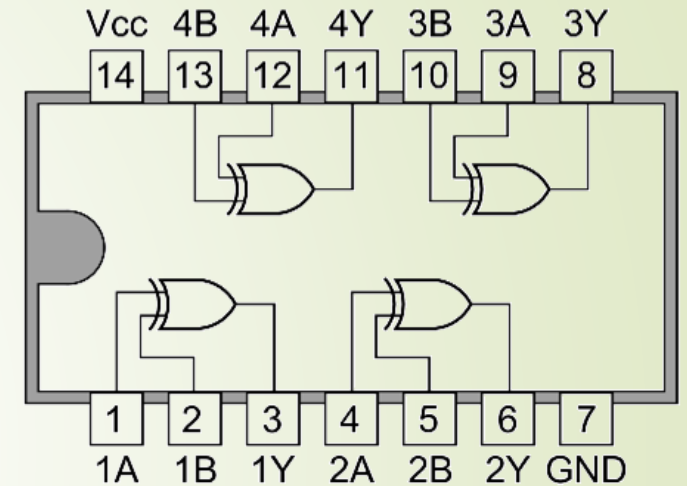
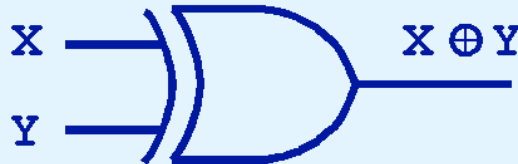
7404
6-Input NOT Gate

Logic Gates – XOR

- Another very useful gate is the **exclusive OR (XOR) gate**.
- The output of the XOR operation is true only when the values of the inputs differ.

X XOR Y

X	Y	$X \oplus Y$
0	0	0
0	1	1
1	0	1
1	1	0

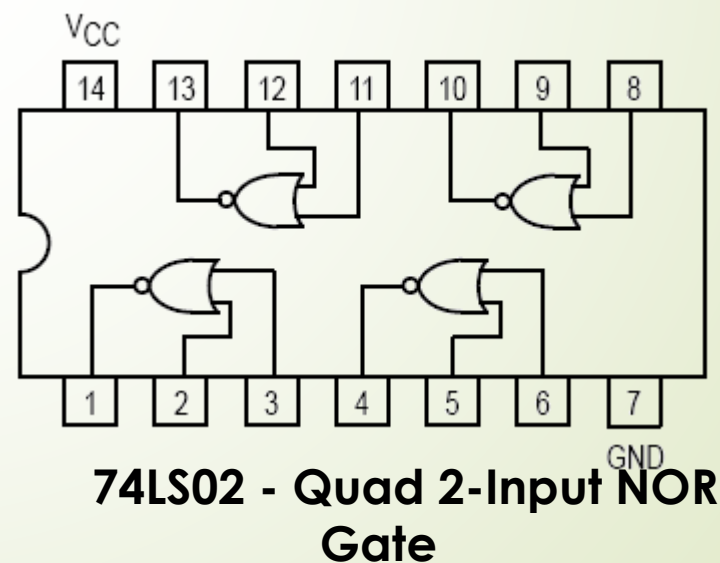
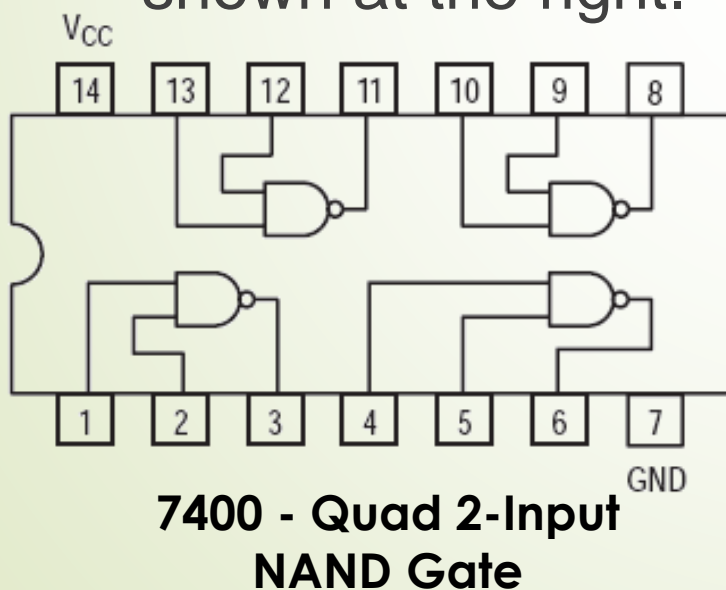


**74HCT86 Quad 2-input
EXCLUSIVE-OR gate**

**Note the special
symbol \oplus for the XOR
operation.**

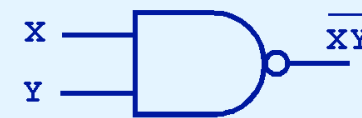
Logic Gates – NAND NOR

- **NAND and NOR** are two very important gates.
- Their symbols and truth tables are shown at the right.



X NAND Y

X	Y	X NAND Y
0	0	1
0	1	1
1	0	1
1	1	0



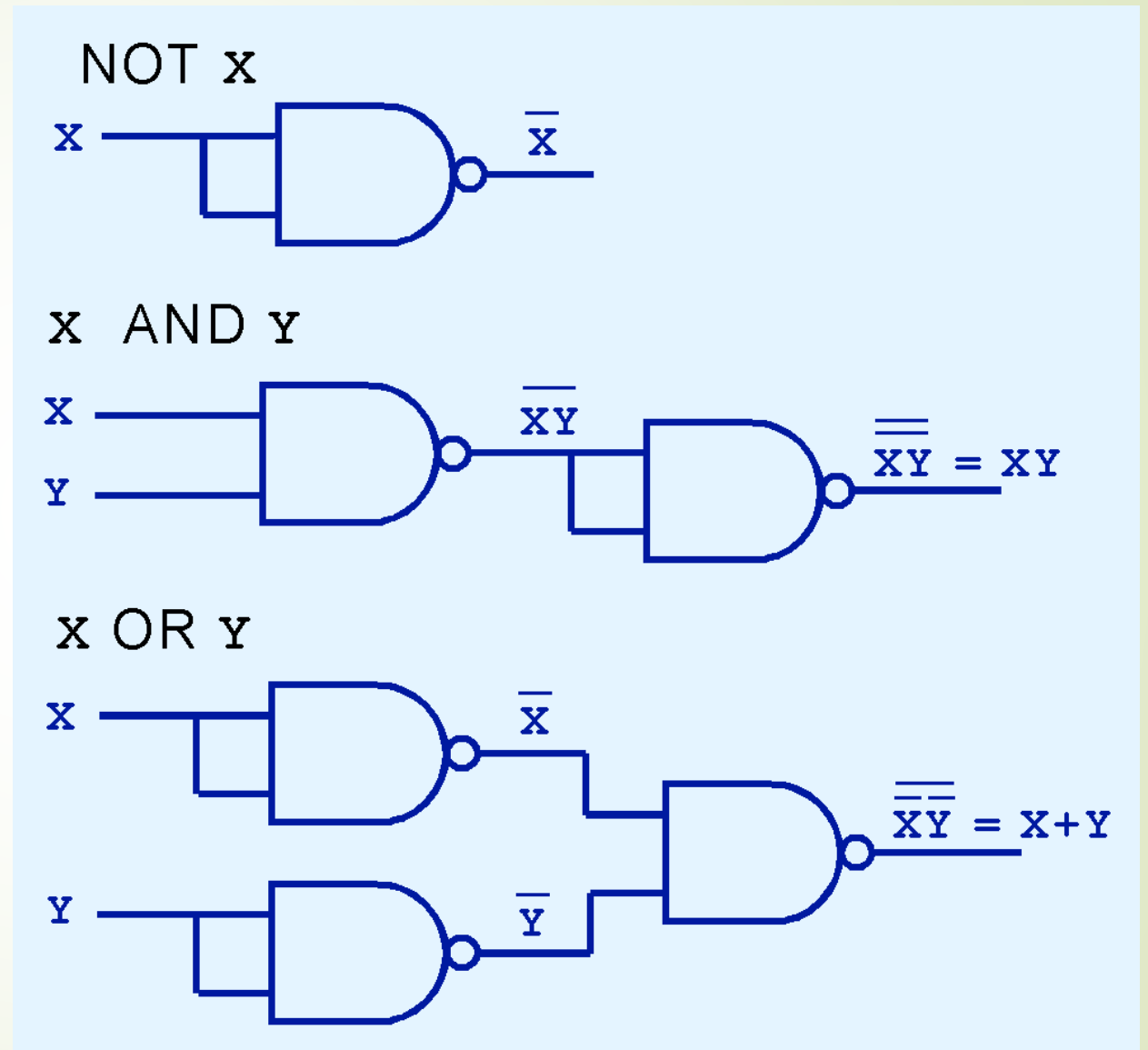
X NOR Y

X	Y	X NOR Y
0	0	1
0	1	0
1	0	0
1	1	0



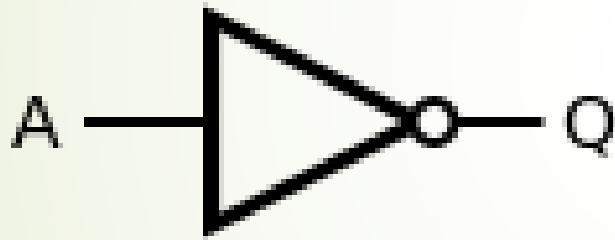
Logic Gates

- NAND and NOR are known as **universal gates** because they are **inexpensive** to manufacture and **any Boolean function can be constructed using only NAND or only NOR gates.**

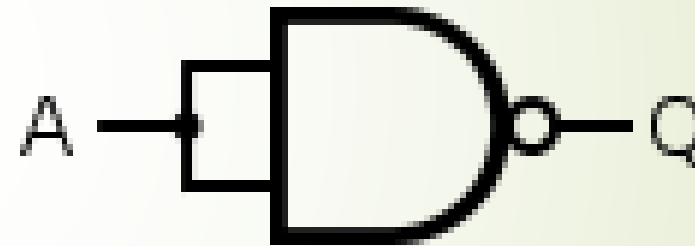


Logic Gates NAND with NOT gate

➡ Target



NAND usage

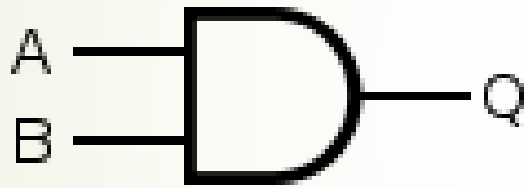


Truth Table

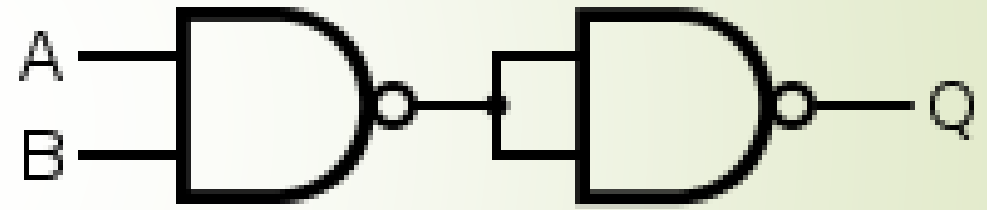
Input A	Output Q
0	1
1	0

Logic Gates NAND with AND

➡ Target



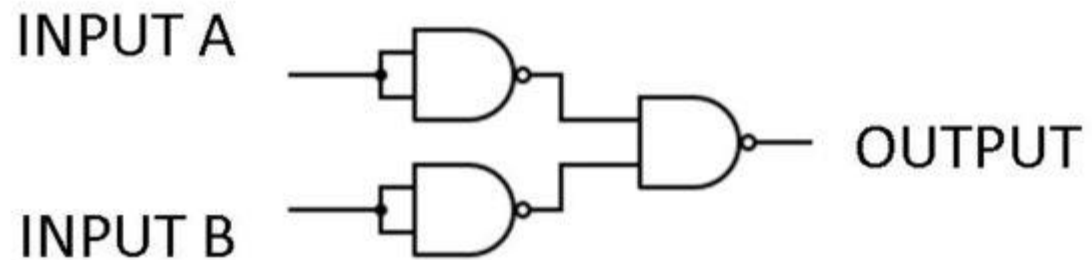
NAND usage



Truth Table		
Input A	Input B	Output Q
0	0	0
0	1	0
1	0	0
1	1	1

Logic Gates NAND with OR

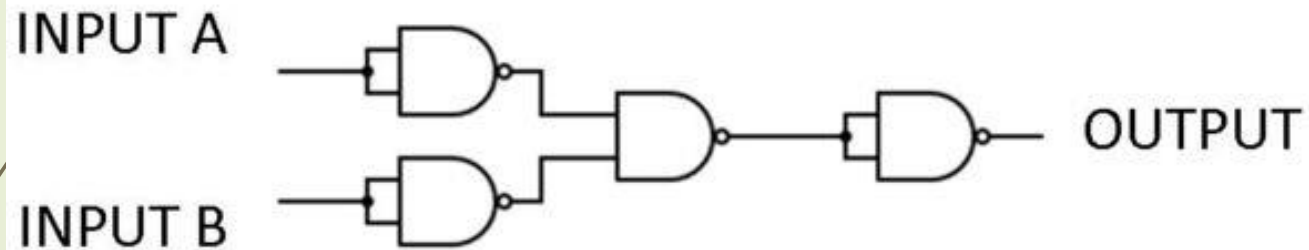
OR gate from NAND gates



NAND (Not AND)		
A	B	S
0	0	1
0	1	1
1	0	1
1	1	0

Logic Gates NAND with NOR Gate

NOR gate from NAND gates

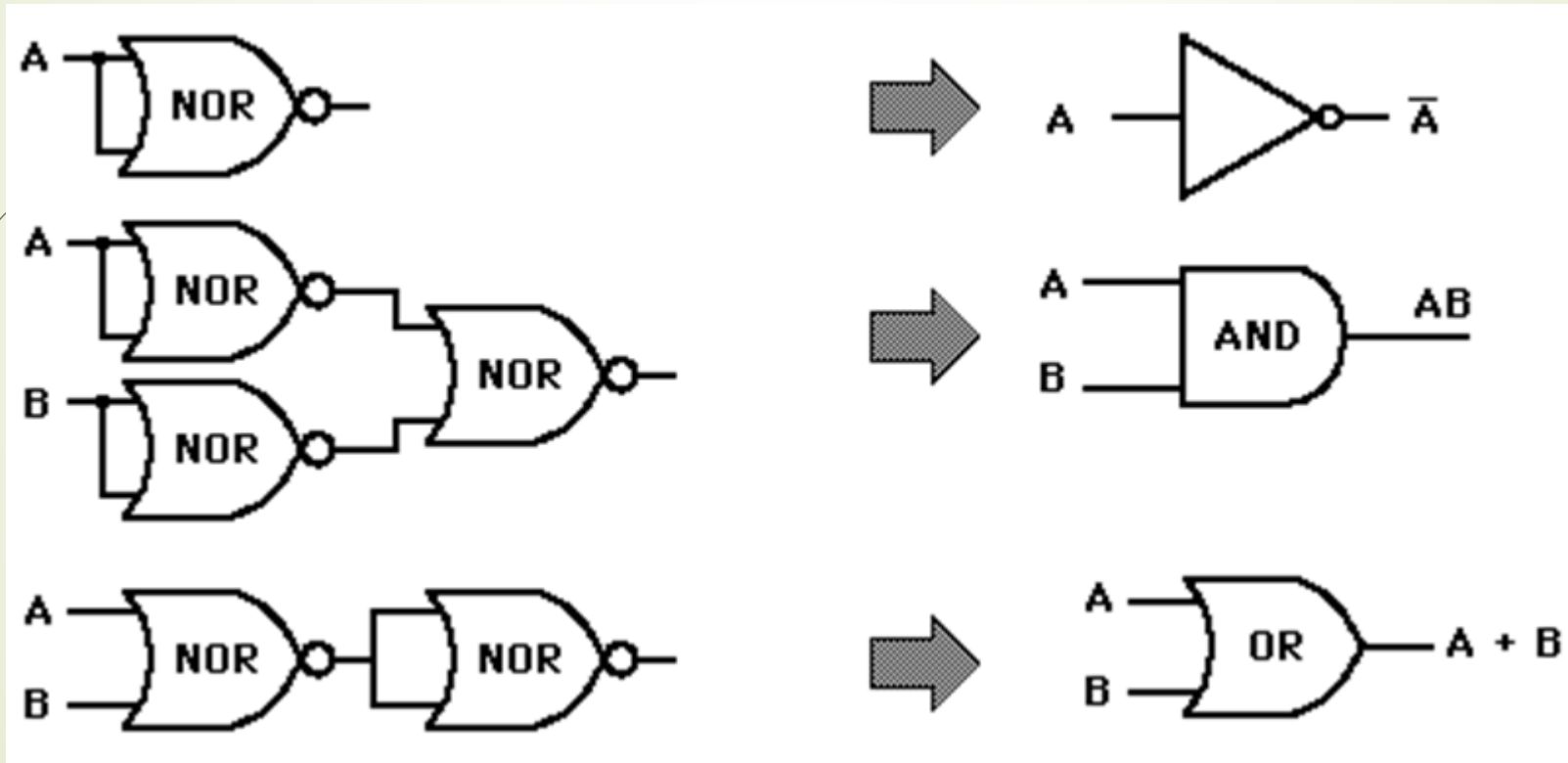
**NAND (Not AND)**

A	B	S
0	0	1
0	1	1
1	0	1
1	1	0

NOR

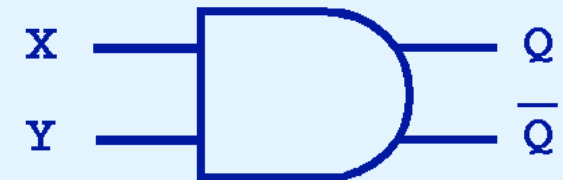
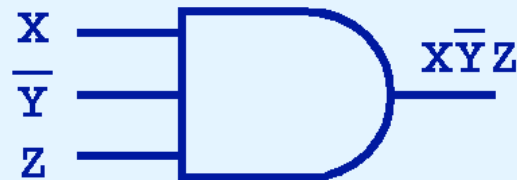
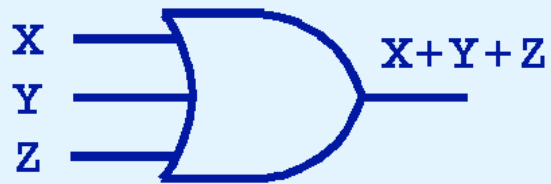
A	B	S
0	0	1
0	1	0
1	0	0
1	1	0

Logic Gates – Creating other gates using NOR gate



Logic Gates

- Gates can have multiple inputs and more than one output.
- A second output can be provided for the complement of the operation.
- We'll see more of this later.



Logic Gates – Example 1

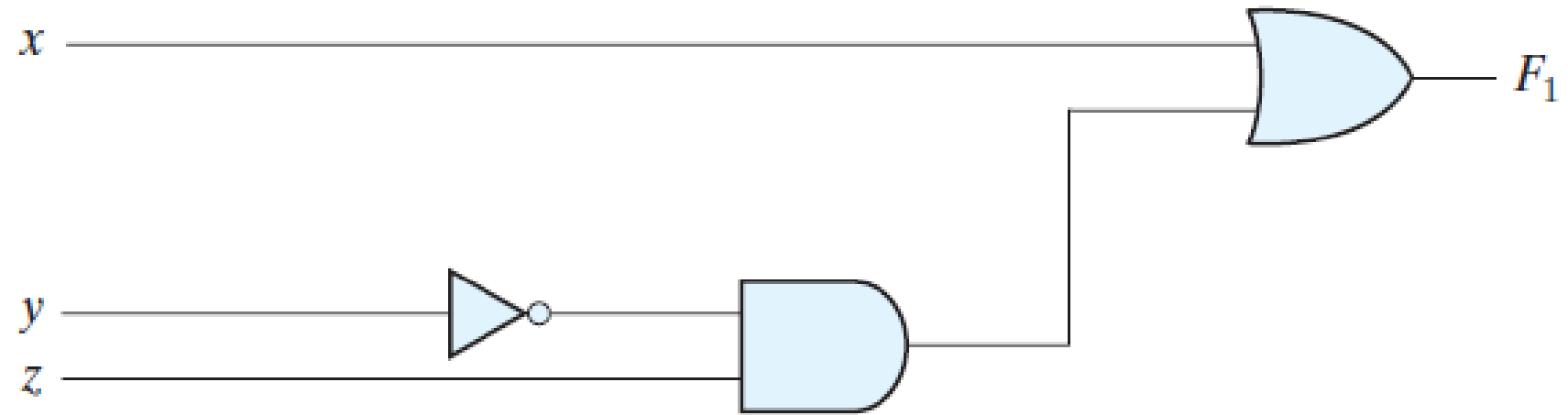
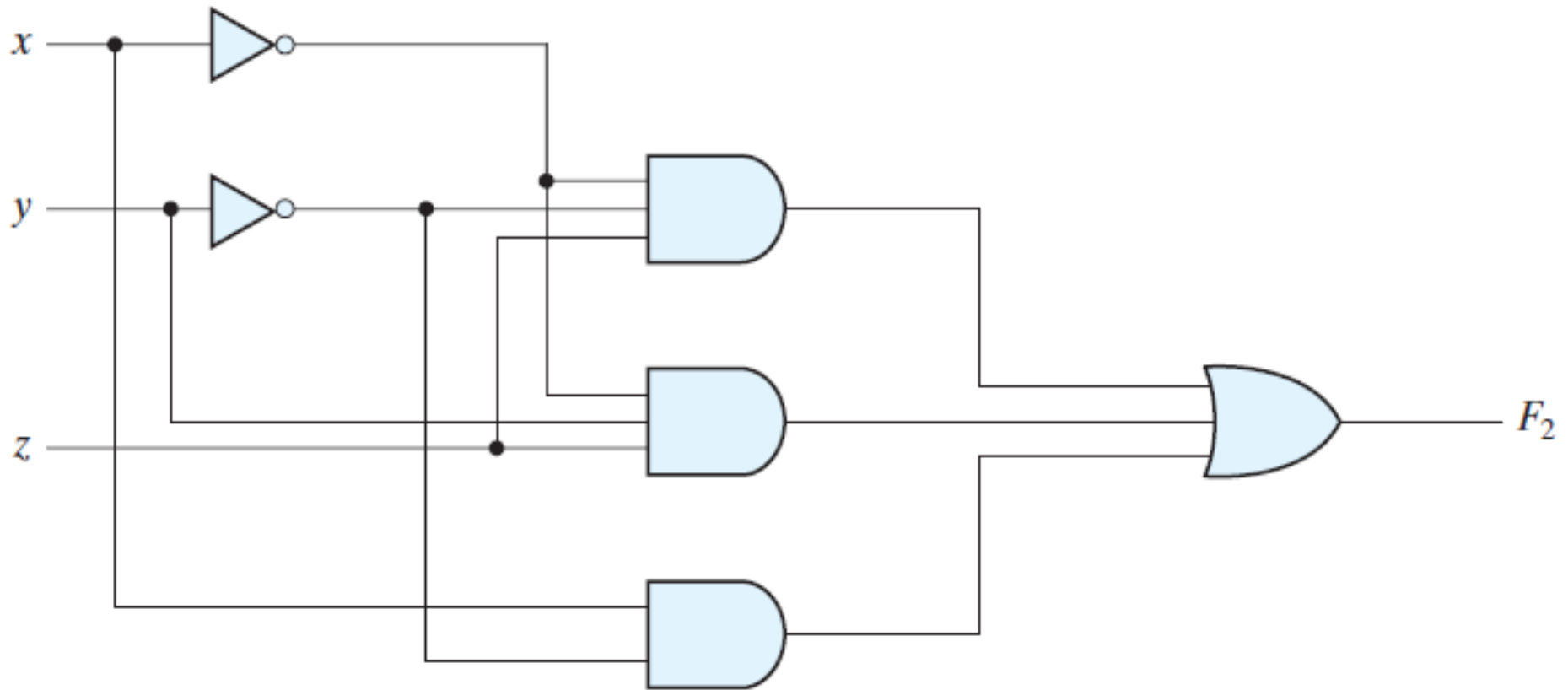


FIGURE 2.1

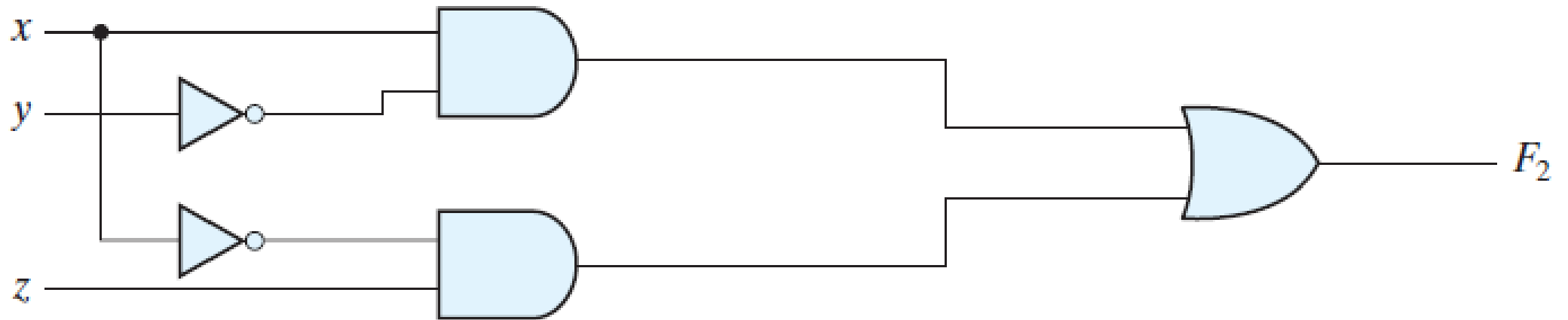
Gate implementation of $F_1 = x + y'z$

Logic Gates – Example 2



(a) $F_2 = x'y'z + x'yz + xy'$

Logic Gates – Example 3



(b) $F_2 = xy' + x'z$